Rotorcraft Structural Integrity and Safety

Federal Aviation Administration

Presented to: Army/NASA

By: Dy Le, Rotorcraft Program Manager

Date: June 06-09, 2006

Agenda - Presentation Outline

- Overview of Rotorcraft Structures Research Requirements
- RCDT R&D Efforts
- HUMS R&D Initiatives

Rotorcraft Structural Integrity and Safety

Activities	FY04	FY05	FY06	FY07
Technical Information to Revise 14 CFR 29.571 to Reflect DT Assessment Criteria	→	→	→	→
Technical Information to Update the Fatigue and DT Assessment Guidance Material in AC's 29-2A & 27-1	→	→	→	→
HUMS Advisory Material & Compliance Guidance for Part 29 and Part 27		→	→	→

Partnerships

- National Rotorcraft Technology Center (NRTC)
- DoD and NASA on HUMS R&D
- European aviation authorities on HUMS activities

Accomplishments

- Completed Phase I RCDT R&D Efforts.
- Developed RCDT and HUMS R&D Strategic (5-10 Year) Plans and Roadmaps.
- Initiated HUMS and RCDT Phase II R&D

Partnerships/Collaborations in Rotorcraft Structures Research

National Rotorcraft Technology Center, Moffett Field, CA

NASA Ames Res. Ctr. Moffett Field, CA

William J. Hughes Technical Center Atlantic City Int'l Airport, NJ

Civil Aviation Authority (CAA)

Center for Rotorcraft Innovation

Sikorsky Stratford, CT

Boeing Philadelphia, PA

Naval Air Warfare Center, Aircraft Division Patuxent River, MD

NASA Langley Res. Ctr., Hampton, VA

Army Vehicle Tech. Ctr., ARL Hampton, VA

Army Aeroflightdynamics Dir., AVRDEC Moffett Field, CA

Rotorcraft Directorate Fort Worth, TX

Bell Fort Worth, TX

NASA Johnson Space Center Houston, TX

A joint rotorcraft program with industry, academia, DoD, and other government research agencies to develop and validate mutually agreed-upon technologies that will address rotorcraft structures design and certification issues.

Rotorcraft Structures Program Goals

- Reduce the number of fatigue cracking of structures leading to potential failure of rotorcraft.
- Assist the Rotorcraft Industry/OEM in addressing RCDT design and certification issues.

- Increase the rate of detection of anomalies during flight.
- Allow rotorcraft OEM/operators install certified HUMS and its accessories on board to obtain data, which can be used for maintenance credits or component fatigue life extension/reduction.

FAA Rotorcraft Structural Integrity & Safety

Rotorcraft Structural Integrity & Safety

Rotorcraft Damage Tolerance

- Bell RCDT, *NRCT/RITA - IA*
- Boeing RCDT, *NRCT/RITA - IA*
- Sikorsky RCDT, *NRCT/RITA - IA*
- RC Threshold Data, *ARL - IA*
- Corrosion on FCG, *NASA LaRC/JSC - IA*
- Life Enhancement, *MSU - Contract*
- FCG Analysis, *MSU - Grant*
- Small Crack Effects, *GiT – RCOE - IA*
- FCG Testing, *NASA JSC - IA*
- Shot Peening/FCG Model, *UCI/SAC - Grant*
- Shot Peening Testing, *WSU - Grant*
- Robust FCG Model, *Cranfield, Army IA*
- DT Computation
- DT Probabilistics/Risk Assessment
- DT FCG Test Methods
- DT Life Enhancement
- Small/Large Crack Database

Health and Usage Monitoring System

- HUMS Degradation, ***NAWCAD - IA***
- HUM FRR, ***ERAU - Contract***
- Detection for Structures, ***Acellent - Contract***
- Mechanical Systems, ***Smiths Aero - Contract***
- HUMS Partition, ***Smiths Aero - Contract***
- HUMS COTS, ***Goodrich - Contract***
- HUMS Flight Testing, ***Sikorsky - Contract***
- Direct Load Measurement
- Wireless Networking
- Vibration Algorithm
- Approaches for Maintenance

Load Monitoring

- Usage Spectrum /Load Monitoring

Fly-By-Wire Flight Control Systems

Projects Summary		
Project Types	FY06 Projects	FY07 Projects
IAs	11	10
Grants	3	1
Contracts	17	16+
TOTAL	31	29+

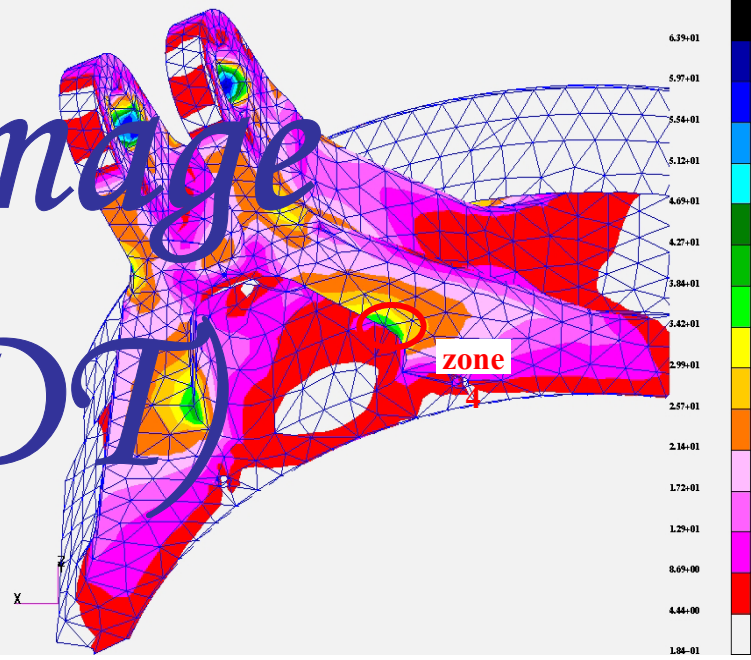
Legends:

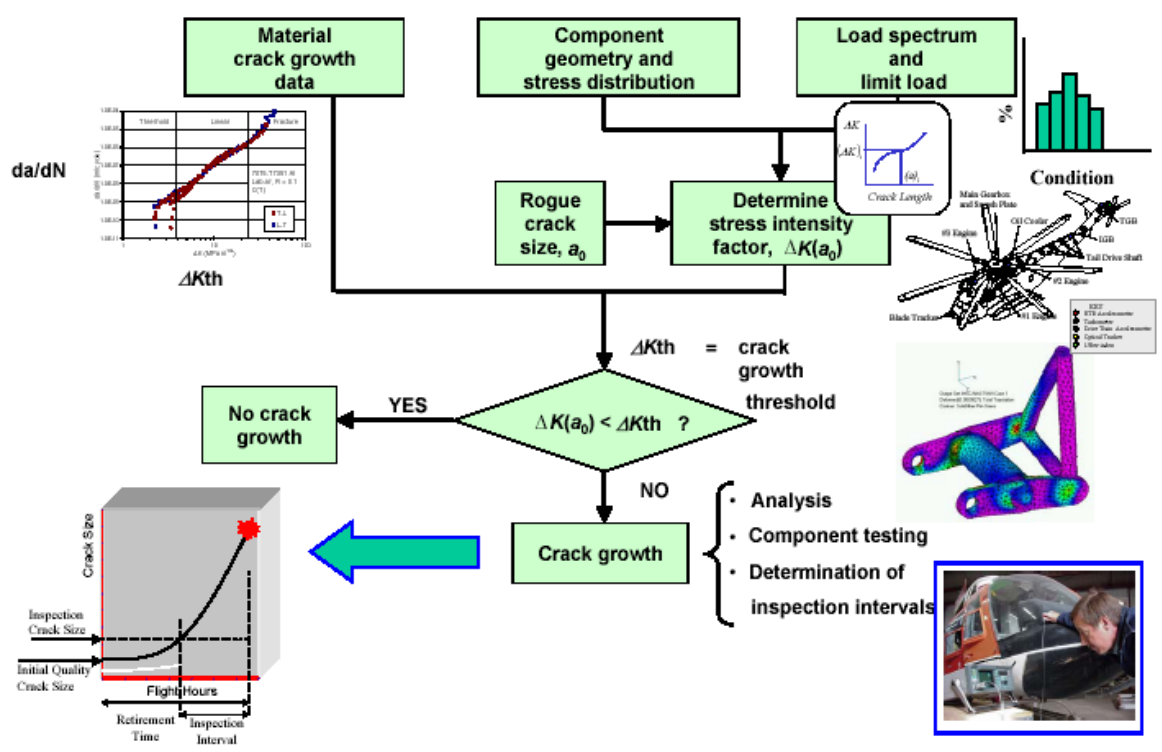
Projects in Black: On-going

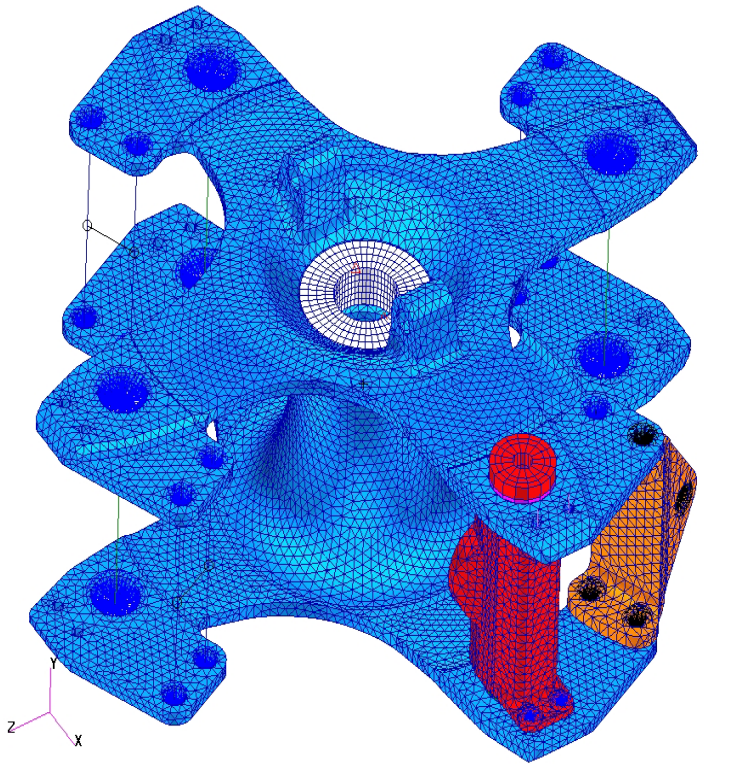
Blue Projects Underlined: To be completed in FY06

Red Projects Underlined: Being awarded in FY06

Rotorcraft Damage Tolerance (RCDT)







RCDT R&D Roadmap

2000 | 2001 | 2002 | 2003 → 2005

FAA Rulemaking — FAA Metallic Structures Rulemaking & AC writing — **NPRM**

decreasing priority

1 RCDT Specific Issues Study → Case Studies

2 Spectrum Development → Usage Monitoring → Usage Monitoring Dev.

3 EIFS Database → Database Dev.

4 Coupon Test Methods → K-th, Long & Short Crack, HCF, & Peened Coupon Database → Database Dev.

5 NDI Survey / POD Studies → NDI Technology Development

6 Certification Test Guidelines → Analysis Alternatives to Cert. Tests → Dev.

7 Life Enhancement Methods → Life Enhancement R&D

8 CGA Dev/Val ; Stress Anal Guides ; HCF/LCF interaction ; K-sol'ns → Residual Stress/WFD R&D

9 Risk Assessment Case Studies → Probabilistic DT R&D

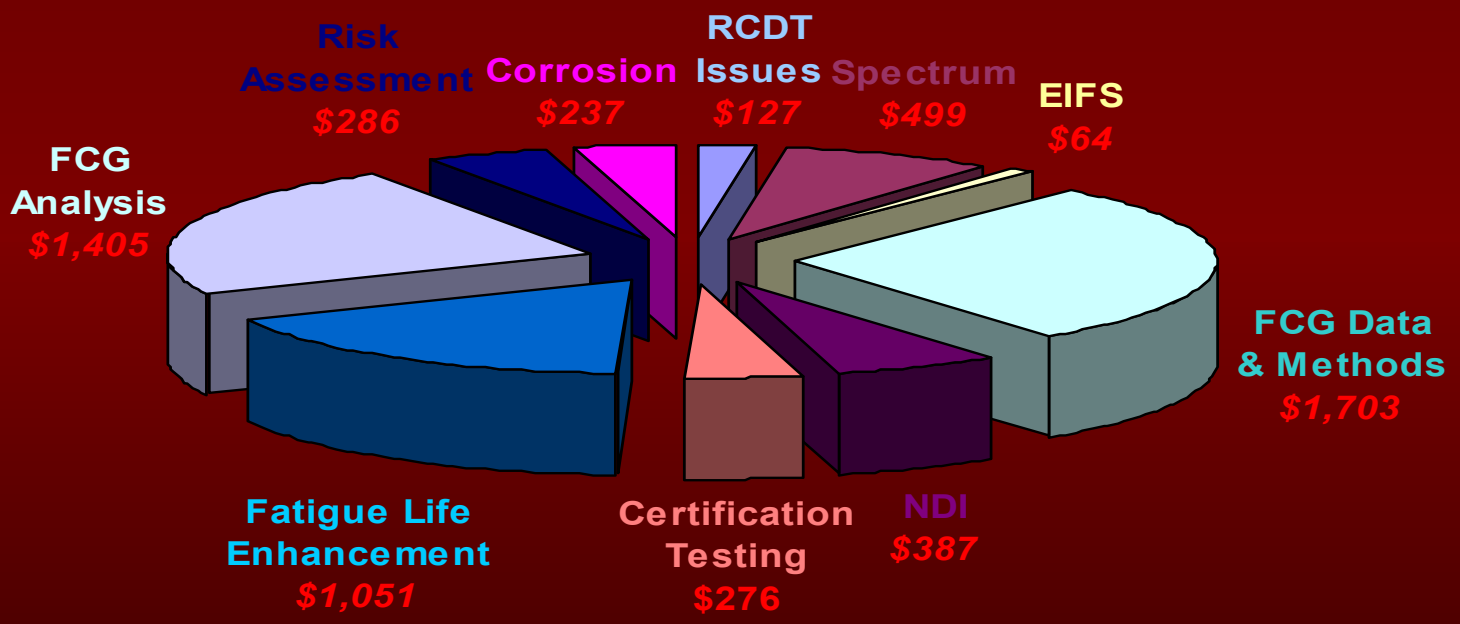
10 Corrosion Control R&D

- Support advisory material
- Compliance issues
- Technology enhancements

Industry Product Development and Field Support Technology Implementation

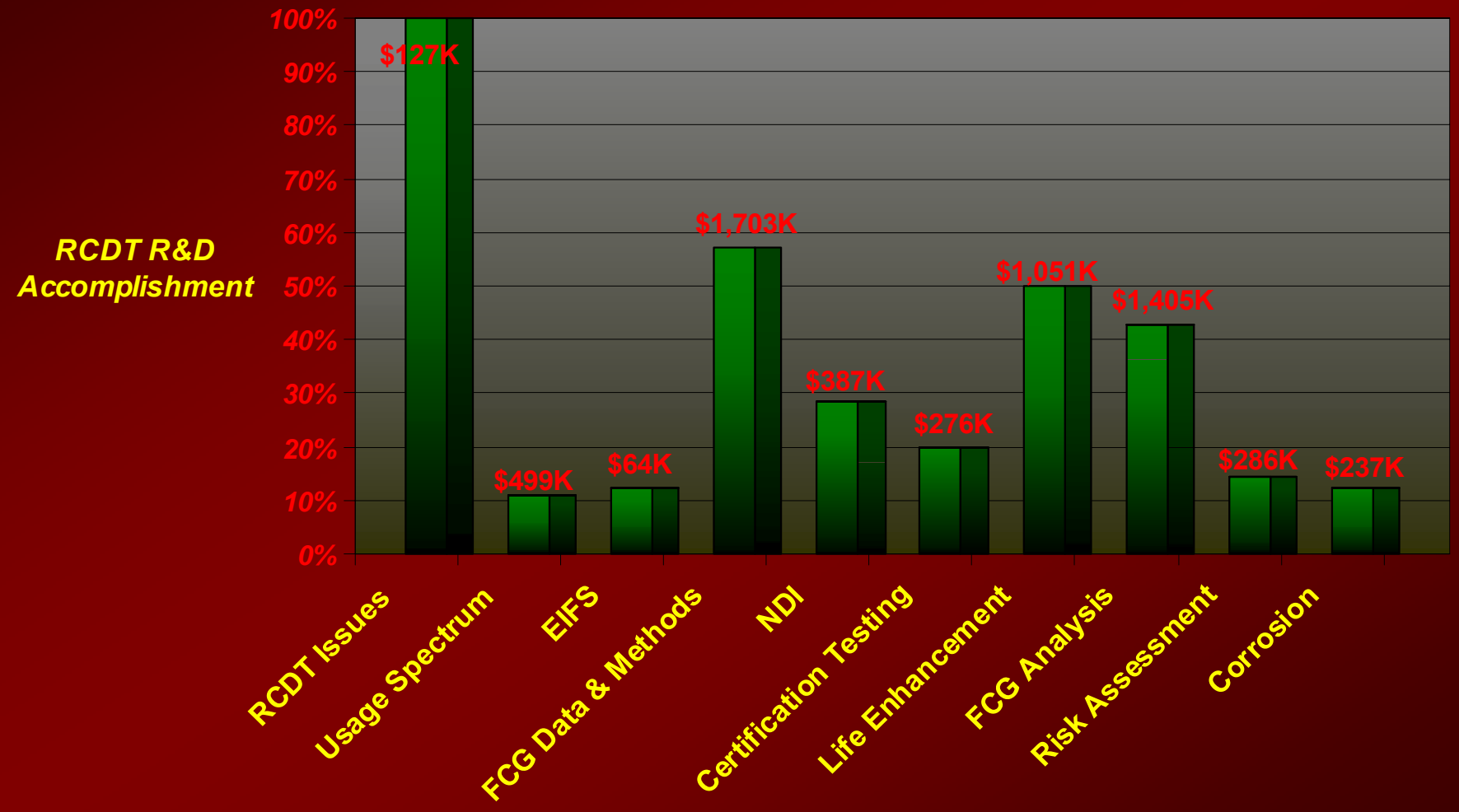
Composite Structures DT R&D, Rulemaking and Advisory Circular (AC) Material

FAA RCDT Phase I R&D Funding ($K)

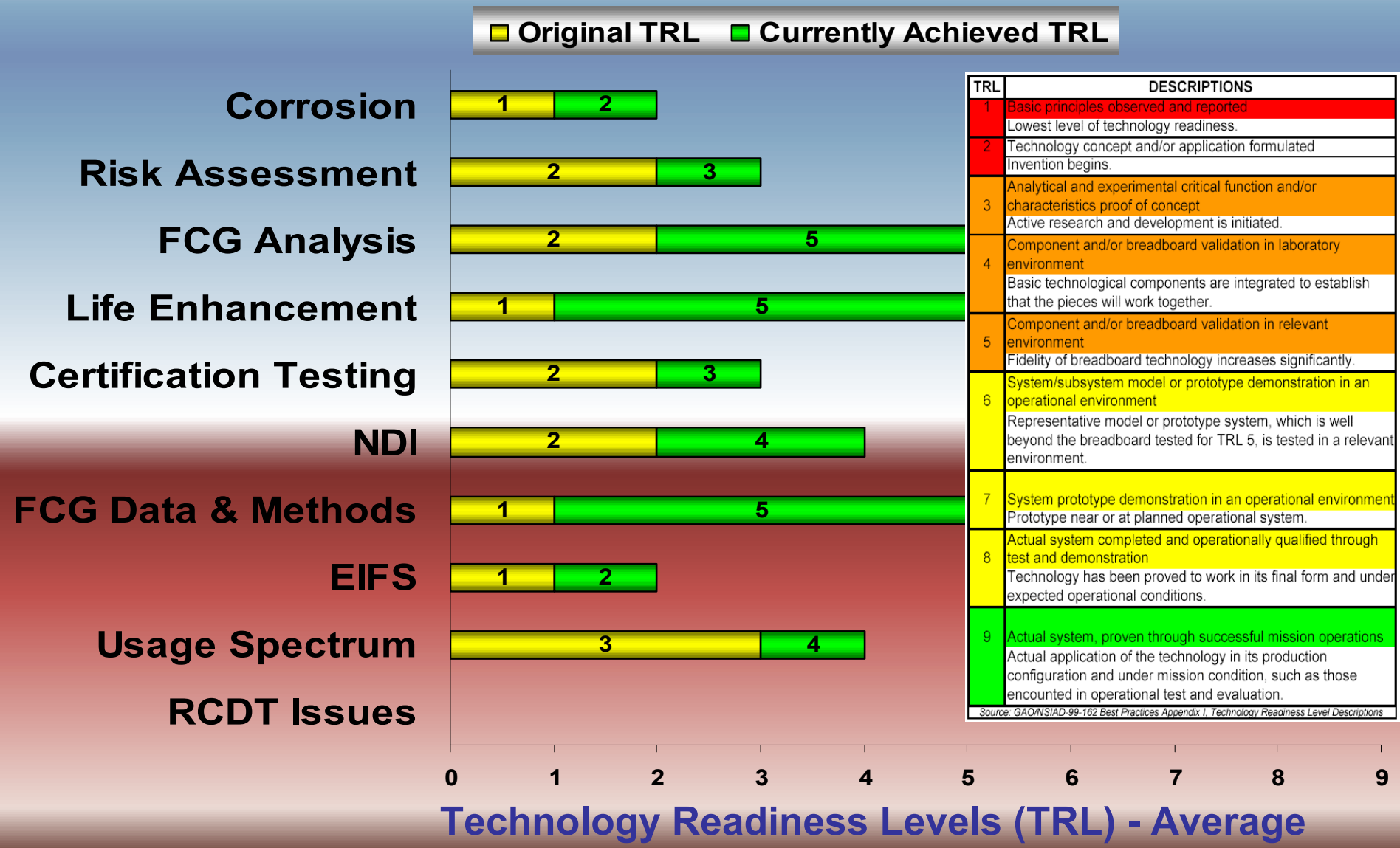


FY00 - FY05 ($6M)

FAA RCDT Research Status and Accomplishment
FY00 - FY05 ($6M)



RCDT TRL Achievements (FY00 - FY05)



TRL	DESCRIPTIONS
1	Basic principles observed and reported Lowest level of technology readiness.
2	Technology concept and/or application formulated Invention begins.
3	Analytical and experimental critical function and/or characteristics proof of concept Active research and development is initiated.
4	Component and/or breadboard validation in laboratory environment Basic technological components are integrated to establish that the pieces will work together.
5	Component and/or breadboard validation in relevant environment Fidelity of breadboard technology increases significantly.
6	System/subsystem model or prototype demonstration in an operational environment Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment.
7	System prototype demonstration in an operational environment Prototype near or at planned operational system.
8	Actual system completed and operationally qualified through test and demonstration Technology has been proved to work in its final form and under expected operational conditions.
9	Actual system, proven through successful mission operations Actual application of the technology in its production configuration and under mission condition, such as those encounted in operational test and evaluation.

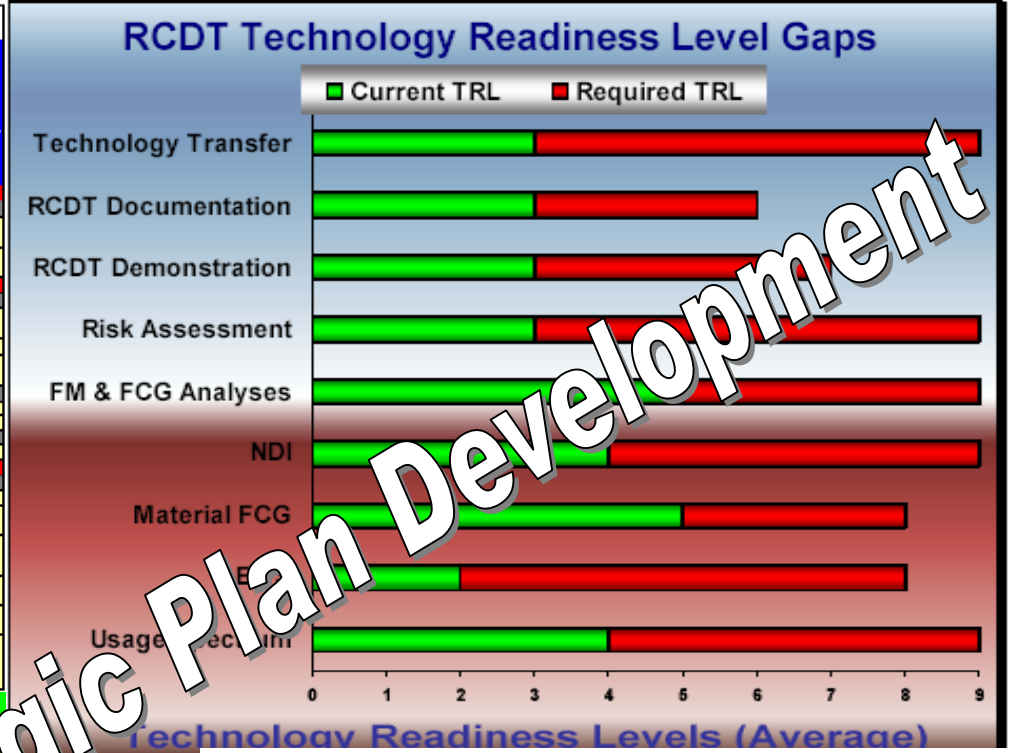
Source: GAO/NSIAD-99-162 Best Practices Appendix I, Technology Readiness Level Descriptions

RCDT R&D Strategic Plan Development

FEDERAL AVIATION ADMINISTRATION

Rotorcraft Damage Tolerance (RCDT) Gap Analysis

		Technology Assessment			Current State of Technology			Regulation Support Criteria		IDENTIFIED
		Current TRL (1 to 9)	Required TRL (1 or 9)	Years To Fully Operational (or to TRL 9)	Technology Risk (0, 1, 2, or 3)	Technology Gaps	Certification Readiness Ready = 0 Not Ready=1	Applicable to RCDT Reg? Yes = 0 No = 1	Is this an R&D task? Yes = 0 No = 1	TECHNOLOGY NEEDS
OVERALL RCDT TECHNOLOGY STATUS		**4**	**7**	**3**	**2**	**3**	**0**	**98%**	**96%**	
Component Stress Distribution		**4**	**7**	**3**	**2**	**3**	**0**	**100%**	**100%**	
Finite Element Methods and Codes		**4**	**7**	**3**	**2.0**	**3**	**0**	**100%**	**100%**	
	Enhancement of FEA complex geometry, non-linear stress field	5	7	3	2	2	1	0	0	FEA Enhancement
	and fracture mechanics codes (integration)	3	7	3	2	4	1	0	0	FEA & FM Interface
Usage and Load Spectrum		**4**	**9**	**3**	**2**	**4**	**0**	**100%**	**100%**	
Usage Data Collection		**5**	**8**	**3**	**2**	**3**	**0**	**100%**	**100%**	
	Establishment of Typical Spectrum Using HUMS	4	9	3	2	5	1	0	0	Establishment of Typical Spectrum Using HUMS
	Usage monitoring using HUMS	7	9	3	1	2	1	0	0	Usage Monitoring
	Sensitivity of FCG to usage/load spectra variations	5	7	2	2	2	1	0	0	FCG & Load Sensitivity
Load Spectrum		**4**	**9**	**5**	**2**	**5**	**0**	**100%**	**100%**	
	Heavy lift components strain survey	4	9	5	2	5	1	0	0	Strain Survey
	Direct Load Measuring Using HUMS	4	9	5	2	5	1	0	0	Using HUMS
RHL		**4**	**9**	**2**	**2**	**4**	**0**	**100%**	**100%**	
	RC Fatigue Life	4	9	2	2	5	1	0	0	Repeated Heavy Lift
Initial Crack Size State		**3**	**6**	**3**	**2**	**3**	**0**	**100%**	**89%**	
Determination of Equivalent Initial Flaw		**3**	**6**	**3**	**2**	**3**	**0**	**100%**	**89%**	
	Establishment of RC Damage Database	2	6	5	3	4	1	0	0	Damage Database
	Update FCG models to make EIFS be independent load levels	4	6	2	2	2	1	0	0	FCG Models
	Assessment of Reliability and Maintainability (R&M) FRACAS and RCDT damage databases	4	6	2	2	2	1	0	1	No
	Determination of Normal Quality and Rogue EIFS Distribution	2	6	5	3	4	1	0	0	Quality and Rogue EIFS Distribution
	Characterization of small initial damage states	2	8	3	3	6	1	0	0	Characterization of small initial damage states
	development and application of EIFS to RCDT design and management for manufacturing and in-service damage threats	2	6	2	3	4	1	0	0	EIFS Development Guidelines



RCDT R&D PRIORITIZATION

IDENTIFIED TECHNOLOGY NEEDS

Significance on Continued Airworthiness	Significance on RCDT AC & Regulation	Significance on Continued Op Safety	Critical to HUMS AC	Ranking Scores of R&D Needs (Max= 3)	Rating Levels
(0, 1, 2, 3)	(0, 1, 2, 3)	(0, 1, 2, 3)	(0, 1, 2, 3)		
32%	23%	27%	18%		

RCDT Project ar... Term

1st 2nd 3rd 4th 5th 6th 7th 8th 9th 10th 11th ->

FY11 FY12 FY13 FY14 FY15 FY16-->

Rating

0	No Value
1	Important
2	Very Important
3	Essential

Calculated Rating Score of Each Prioritization
Individual Rating Score × Weighing Percentage

Composite Rating Score of Each Identified R&D Task
Summation of All Ranking Scores
For Each Identified R&D Task

Prioritization Scheme

Composite Rating Scores	Rating Level	Priority
0.0	No Value	Not selected
0.1	No Value	Not selected
0.2	No Value	Not selected
0.3	No Value	Not selected
0.4	No Value	Not selected
0.5	No Value	Not selected
0.6	Long-Term, 10th	10
0.7	Long-Term, 10th	10
0.8	Long-Term, 9th	9
0.9	Long-Term, 9th	9
1.0	Important	8
1.1	Important-Long-Term, 8th	8
1.2	Important-Long-Term, 7th	7
1.3	Important-Long-Term, 7th	7
1.4	Important-Long-Term, 6th	6
1.5	Important-Long-Term, 6th	6
1.6	Important	5
1.7	Important	5
1.8	Important	5
1.9	Important	4
2.0	Very Important	4
2.1	Very Important	4
2.2	Very Important	3
2.3	Very Important	3
2.4	Very Important	3
2.5	Very Important	2
2.6	Very Important	2
2.7	Very Important	2
2.8	Very Important	1
2.9	Very Important	1
3.0	Essential	1

Example

RCDT R&D	Continued Airworthiness	AC & Regulation	Op Safety	Critical to HUMS AC	Composite Rating Scores	Rating Levels
Strain Survey	3	3	3	3	3.0	Essential
	0.96 +	0.69 +	0.81 +	0.54 =	3.0	

GAO Technology Readiness Levels

Normally at TRL 9, but can be lower

Years to bring technology to required TRL

Technology Maturation Risk

(Current – Required) TRL

Certified?

Technology Maturation Risk (TMR)

TRL	Risk	TMR
0	High	3
1	High	3
2	High	3
3	Medium	2
4	Medium	2
5	Medium	2
6	Low	1
7	Low	1
8	Low	1
9	No Risk	0

Rotorcraft Damage Tolerance (RCDT) Gap Analysis

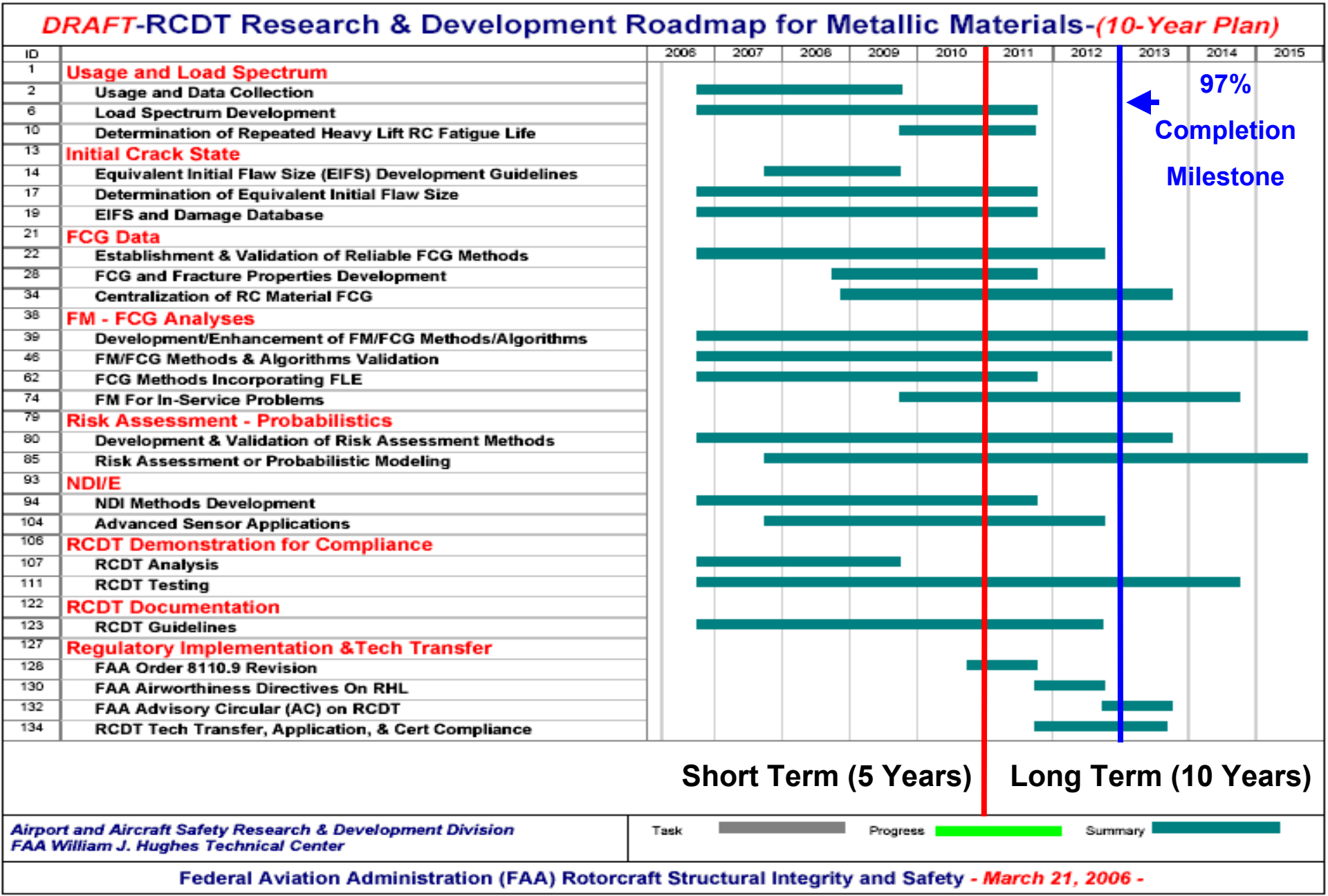
	Technology Assessment			Current State of Technology			Regulation Support Criteria		IDENTIFIED
	Current TRL (1 to 9)	Required TRL (1 or 9)	Years To Fully Operational (or to TRL 9)	Technology Risk (0, 1, 2, or 3)	Technology Gaps	Certification Readiness Ready = 0 Not Ready=1	Applicable to RCDT Reg? Yes = 0 No = 1	Is this an R&D task? Yes = 0 No = 1	TECHNOLOGY NEEDS

FAR 27.571 & 29.571

Must be research in nature

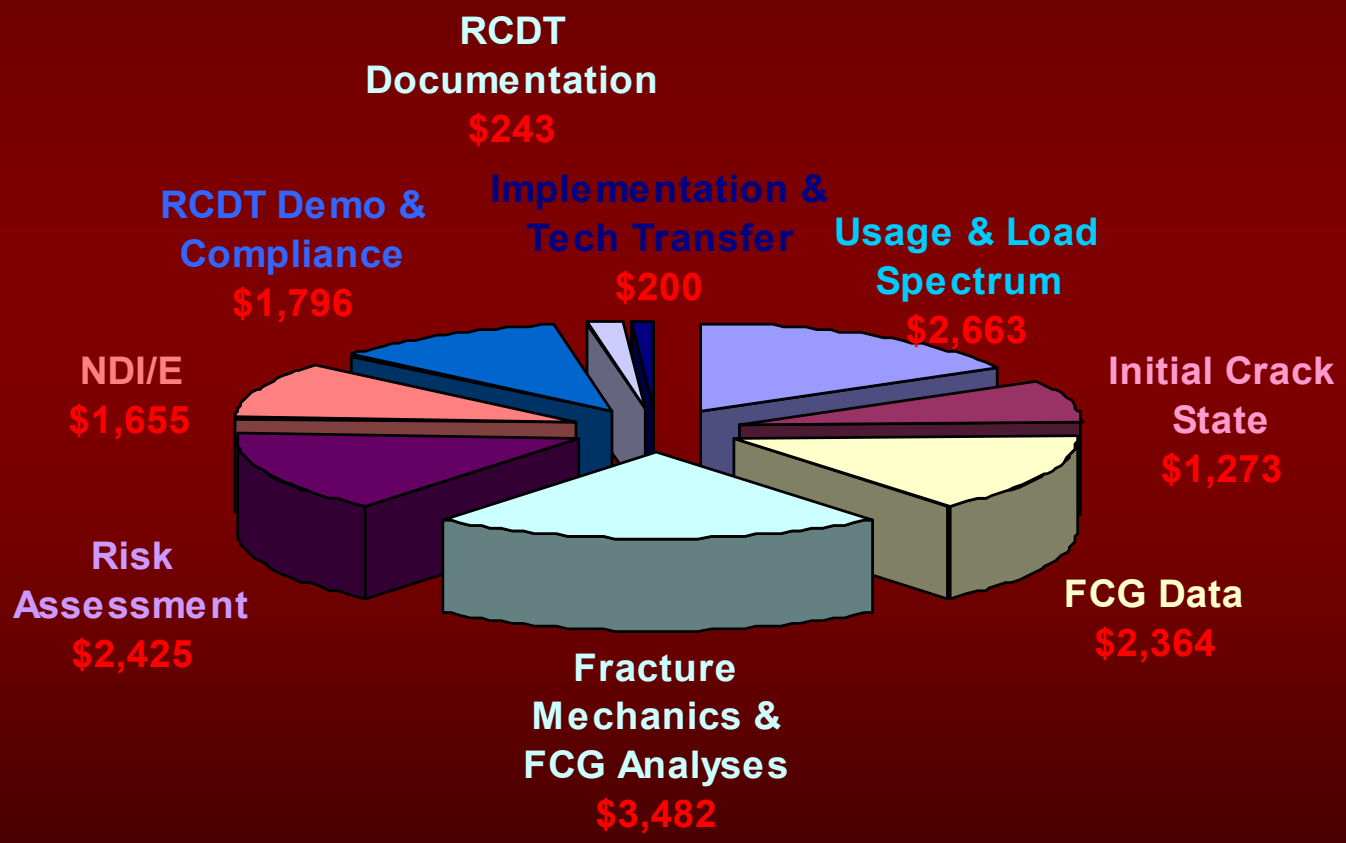
Selected for prioritization

RCDT R&D Roadmap

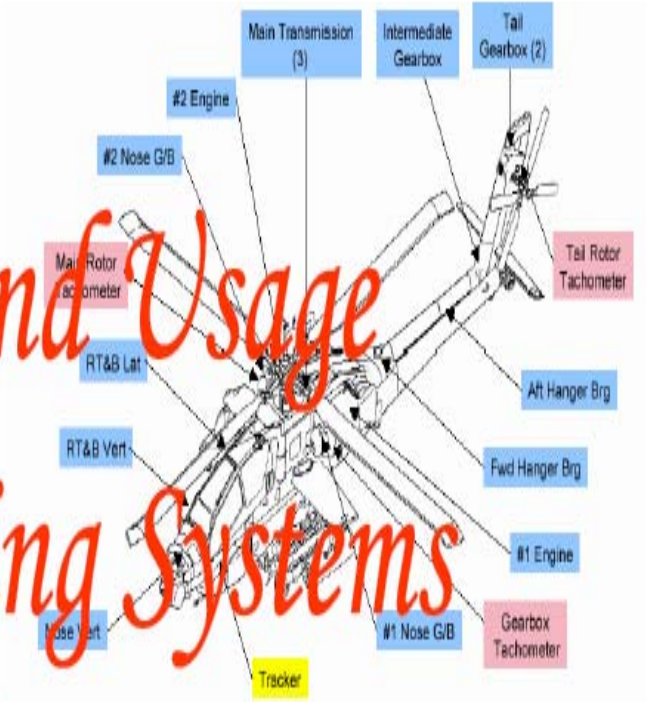


FAA RCDT R&D 10-Year ROM ($K)
$16M

FAA RCDT R&D 10-Year ROM ($K)
FY06 - FY15
$16M



Health and Usage Monitoring Systems (HUMS)



CHAPTER 3
AIRWORTHINESS STANDARDS
TRANSPORT CATEGORY ROTORCRAFT

MISCELLANEOUS GUIDANCE (MG)

AC 29 MG 15. AIRWORTHINESS APPROVAL OF ROTORCRAFT HEALTH USAGE MONITORING SYSTEMS (HUMS)

a. Purpose. The purpose of this section of the AC (AC 29 MG 15) is to provide guidance to achieve airworthiness approval for rotorcraft Health and Usage Monitoring System (HUMS) installation, credit validation, and Instructions for Continued Airworthiness (ICA) for the full range of HUMS applications. Mandatory terms used in this section of the AC, such as "must", are terms used only in the sense of ensuring the applicability of these particular methods of compliance when the acceptable means of compliance described herein are used. This section of the AC does not change regulatory requirements and does not authorize changes in or exceptions from regulatory requirements. This section of the AC establishes an acceptable means, but not the only means of certifying a rotorcraft HUMS. AC 29 MG 15 addresses the most complex/extensive HUMS; systems of lesser complexity may be addressed by use of only the parts of this section of the AC that are pertinent. HUMS applications in the Catastrophic criticality category are not addressed herein.

- ref: ***http://www2.faa.gov/certification/aircraft/Rot_Pol_Hums.htm***

"The purpose of this section of the AC (AC 29 MG 15) is to provide guidance to achieve airworthiness approval for rotorcraft Health and Usage Monitoring System (HUMS) installation, credit validation, and Instructions for Continued Airworthiness for the full range of HUMS applications"

FAA-Certified HUMS for Civil Rotorcraft

System Components

AIRBORNE

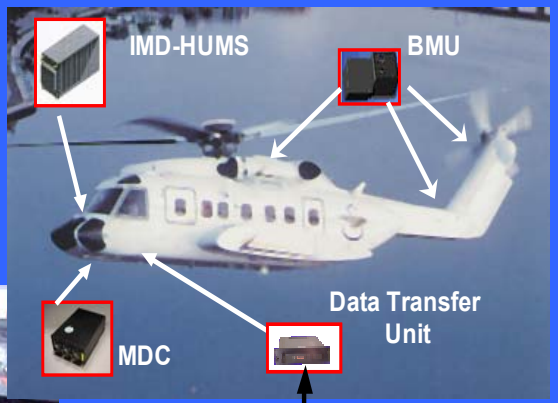
IMD-HUMS

MDC

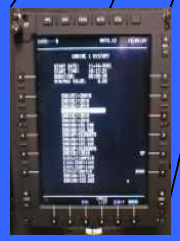
BMU

CV/FDR

Level B HUMS Software



HUMS Development Lab



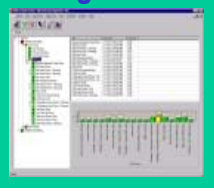
On-Board Display

PCMCIA Card

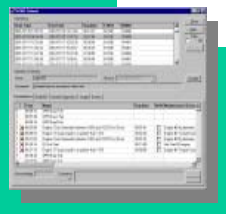
GROUND STATION

Rotor Track & Balance

Drivetrain Diagnostics



Debrief & Exceedance Display



Certified components

Uncertified components

HUMS Assessment Results

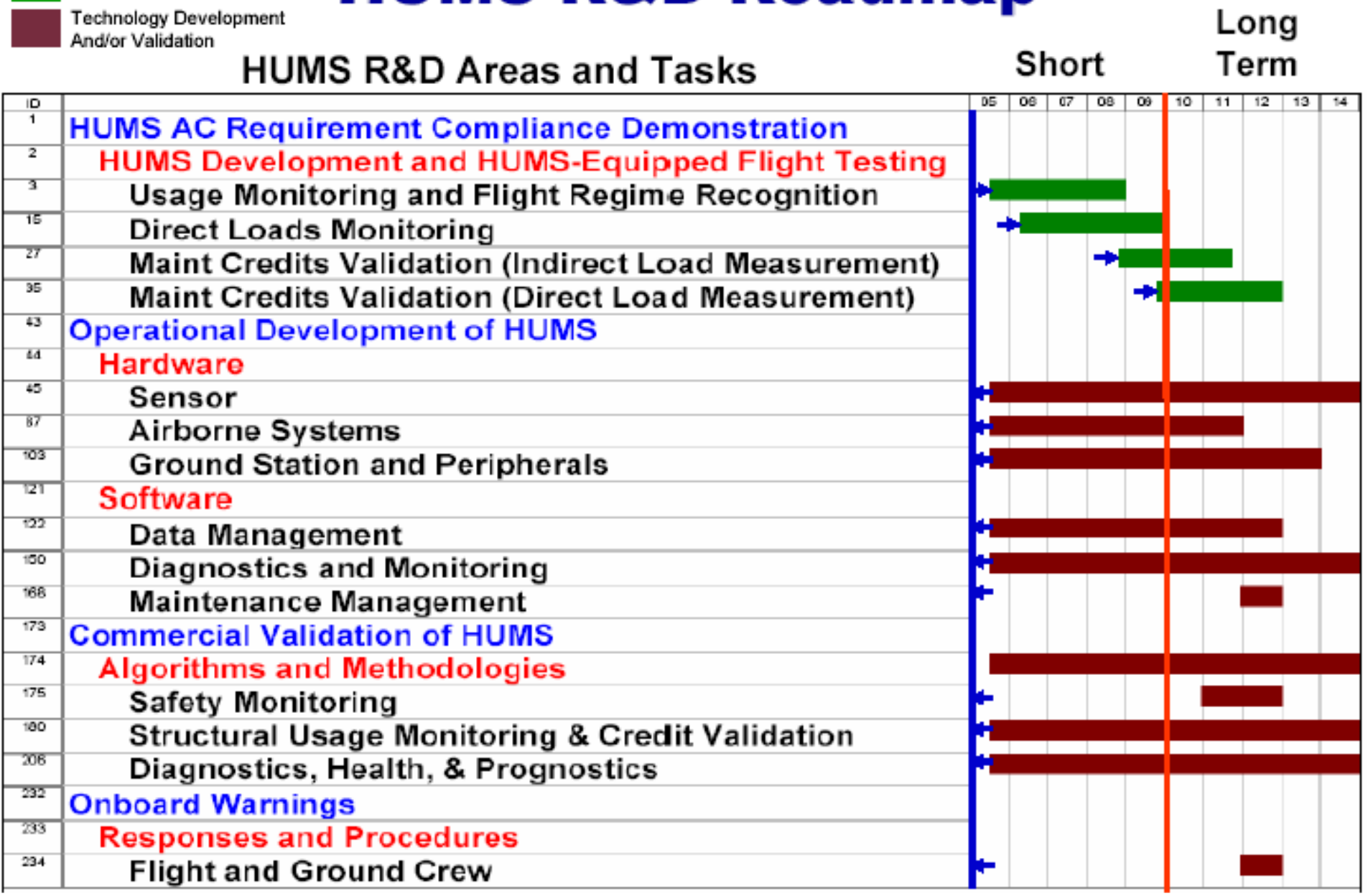
HUMS SUB-CATEGORIES	Certification Readiness	Applicability to HUMS AC	R&D
Sensor	33%	72%	100%
Airborne Systems	23%	77%	77%
Ground-Based Stations and Accessories	29%	100%	86%
Data Management and Operation	8%	92%	92%
Diagnostics and Monitoring	27%	91%	100%
Maintenance Management	40%	80%	80%
Safety Monitoring	17%	83%	50%
Structural Usage Monitoring and Credit Validation	12%	59%	88%
Diagnostics, Health, and Prognostics	13%	47%	100%
Continued Airworthiness Instructions	0%	100%	0%
On-Board Warnings, Responses and Procedures	0%	100%	100%
Overall HUMS Assessment:	**18%**	**82%**	**79%**

Legends:

Technology Demonstration

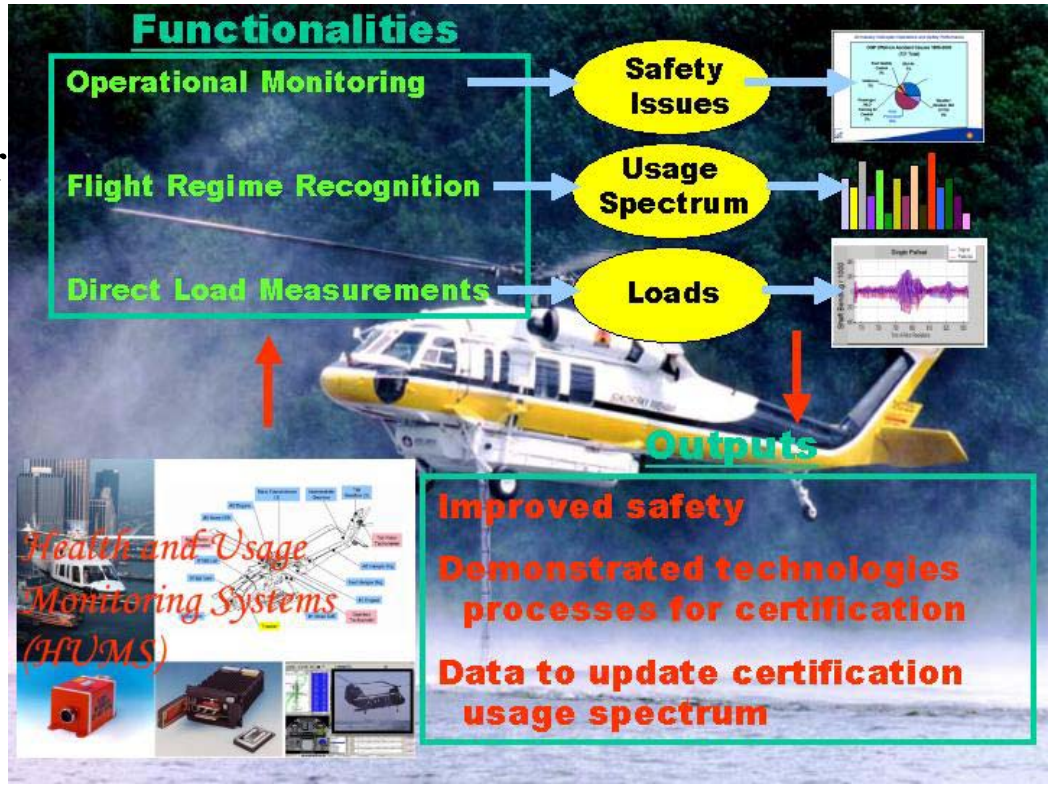
Technology Development And/or Validation

HUMS R&D Roadmap



HUMS AC Compliance Demonstration

- **Requirements/Objectives:**
  - Demonstrate validated technologies/methodologies for certification using AC-29-2C, Section MG-15 (HUMS AC).
    - Usage and flight regime recognition
    - Load monitoring
    - Maintenance credit validation



- **Technical Approaches:**
  - Establish intended purpose of HUMS.
  - Develop certification/mitigation strategies to address AC requirements.
  - Conduct HUMS-equipped flight tests.

HUMS AC Requirement Compliance Demonstration

HUMS R&D Areas and Tasks

Short Long Term

ID		05	06	07	08	09	10	11	12	13	14
1	HUMS Development and Equipped-Flight Testing										
2	Usage Monitoring and Flight Regime Recognition										
14	Direct Loads Monitoring										
26	Maint Credits Validation (Indirect Load Measurement)										
34	Maint Credits Validation (Direct Load Measurement)										

Priority: High Medium Low

Operational Development of HUMS

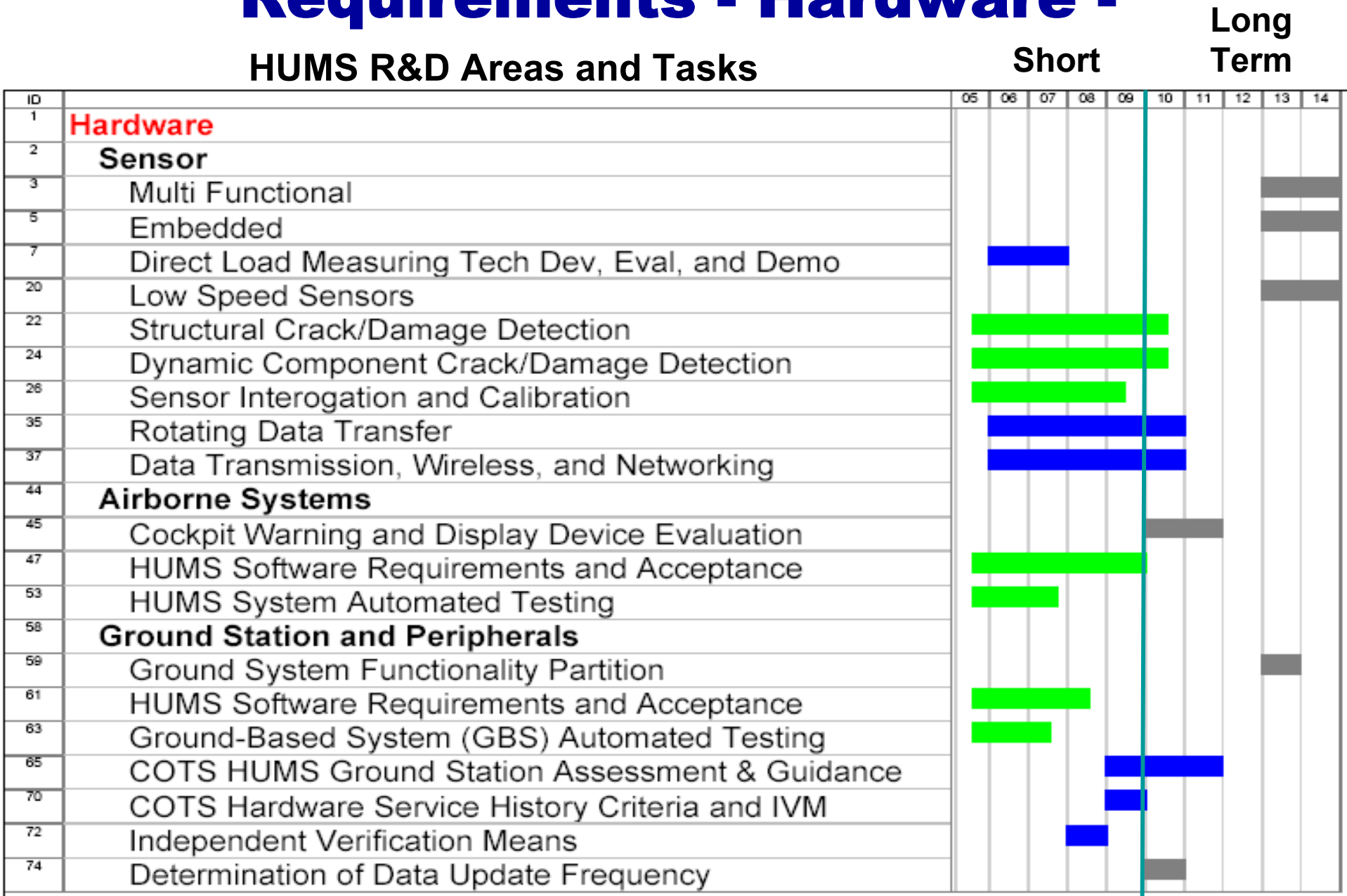
- **Requirements/Objectives:**
  - Develop HUMS airborne and ground-based hardware and software requirements and processes for qualification and certification per HUMS AC.

Outputs

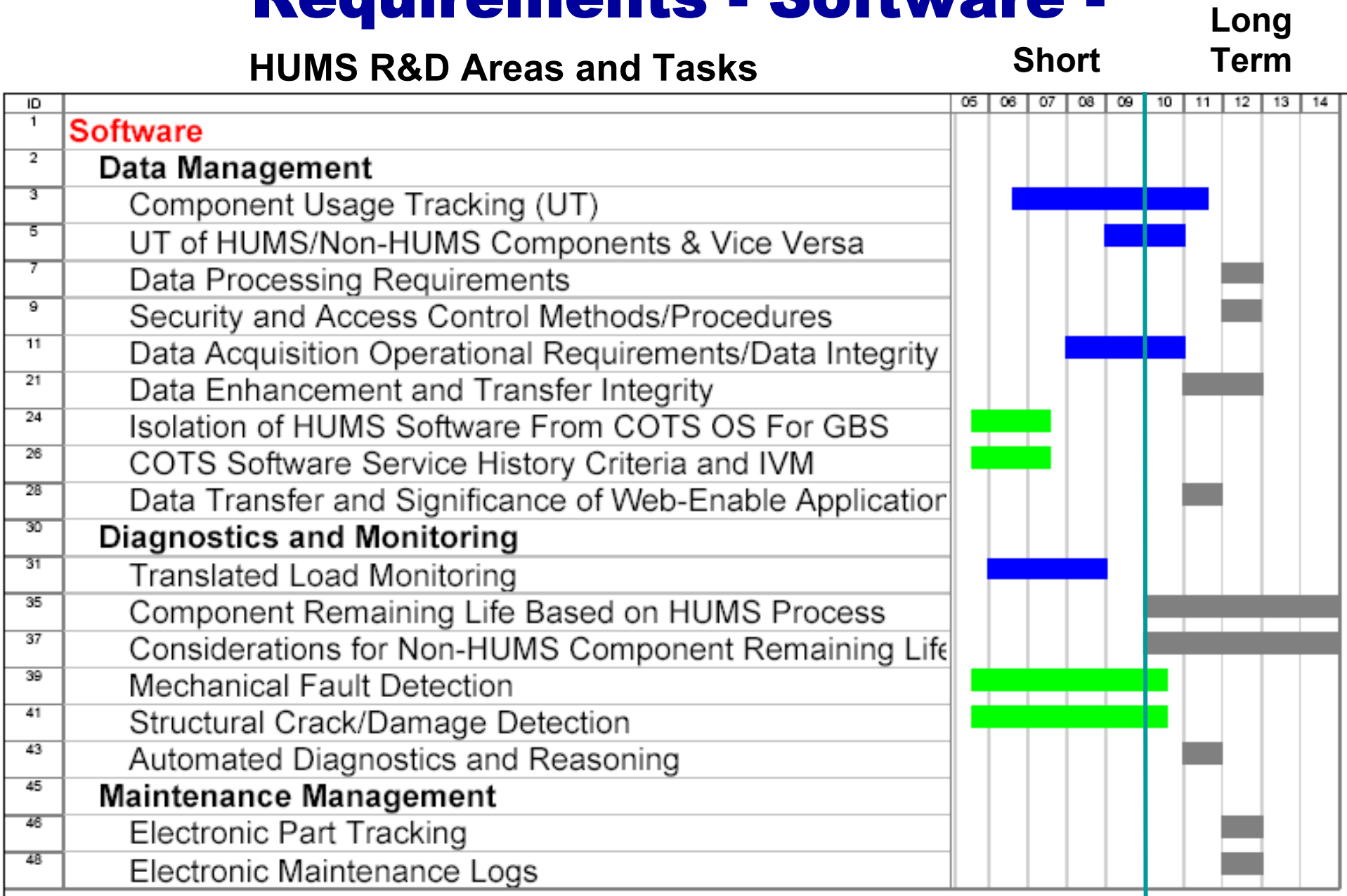
Operational requirement inputs for HUMS qualification and certification per HUMS AC

- **Technical Approaches:**
  - Establish requirements for direct load measuring – advanced sensors.
  - Develop requirements for mechanical and structural fault detection and isolation.
  - Develop software requirements and acceptance criteria.
  - Assess commercial-of-the-shelf ground-based station.

Development of HUMS Operational Requirements - Hardware -

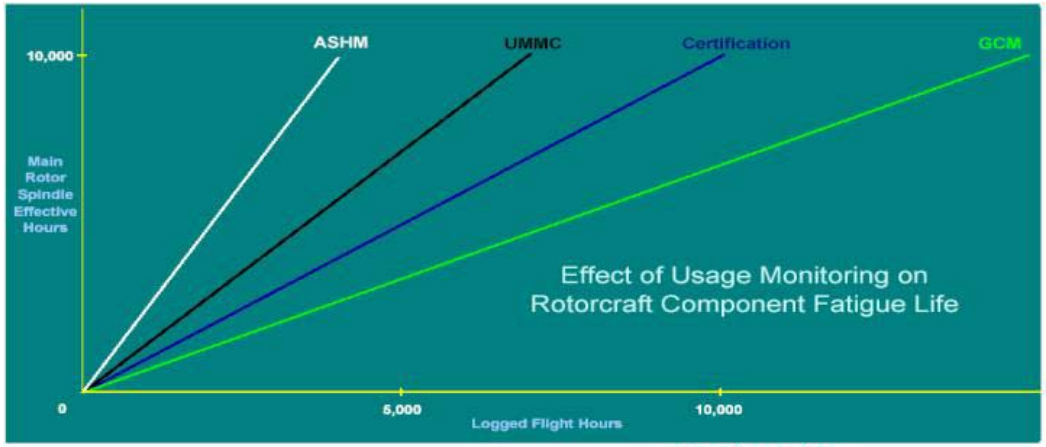


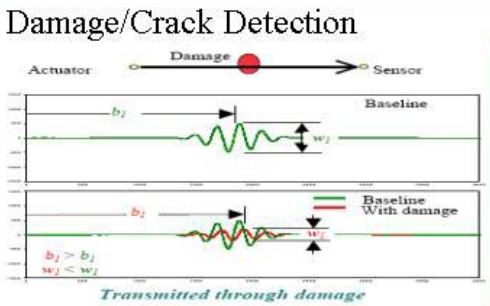
Development of HUMS Operational Requirements - Software -



Commercial Validation of HUMS

- **Requirements/Objectives:**
  - Validate technologies including algorithms, methodologies, and processes for usage monitoring and maintenance credit per HUMS AC.





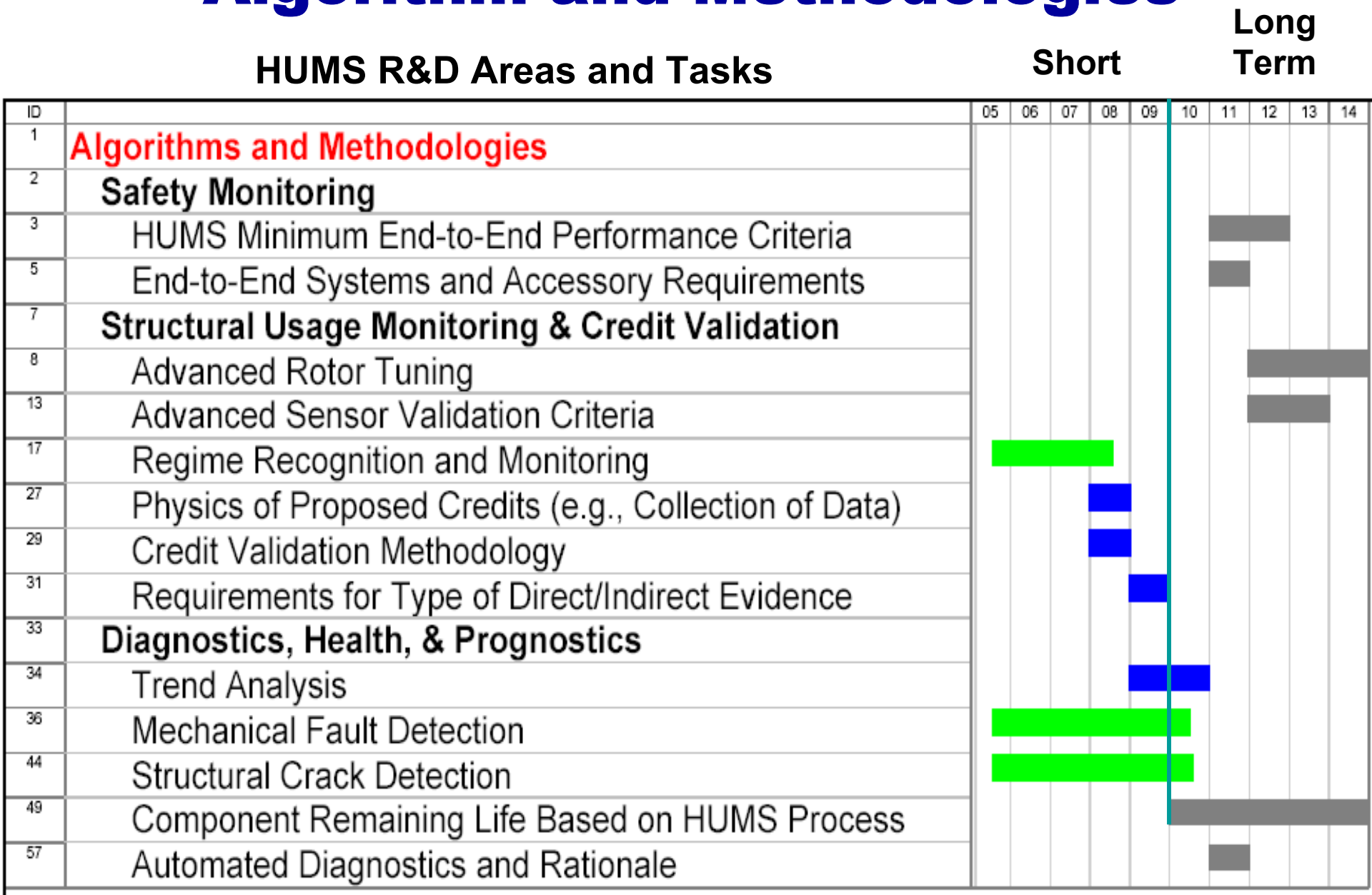
Outputs

Certification Compliance Guidelines

- **Installation**
- **Maintenance credit validation**
- **Instructions for continued airworthiness**

- **Technical Approaches:**
  - Validate flight regime recognition algorithms and methodologies for usage-based maintenance.
  - Validate mechanical and structural fault detection and isolation technologies.
  - Establish technologies to calculate component remaining life based on HUMS process.

Commercial HUMS Validation
- Algorithm and Methodologies -



HUMS Onboard Warnings

Technical Objectives:

- Assessment of onboard display devices to determine their reliability, functionality, and required response or action to displayed/audible advisories/warnings

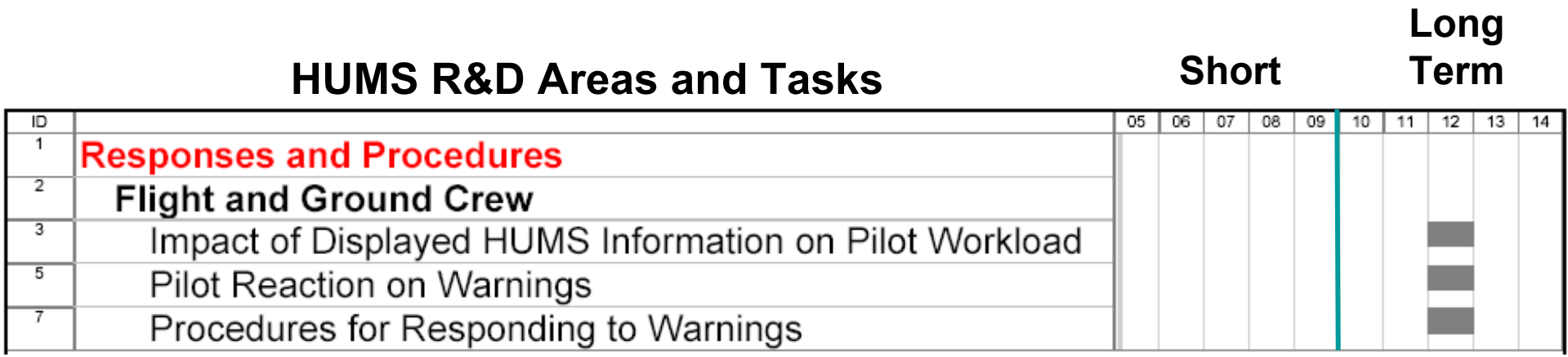
Technical Approaches:

- Evaluate types of devices and information to be displayed or audible.
- Assess pilot interface with operational aspects of the system.
- Study pilot's response or reaction to displayed/audible advisories/warnings.

Outputs:

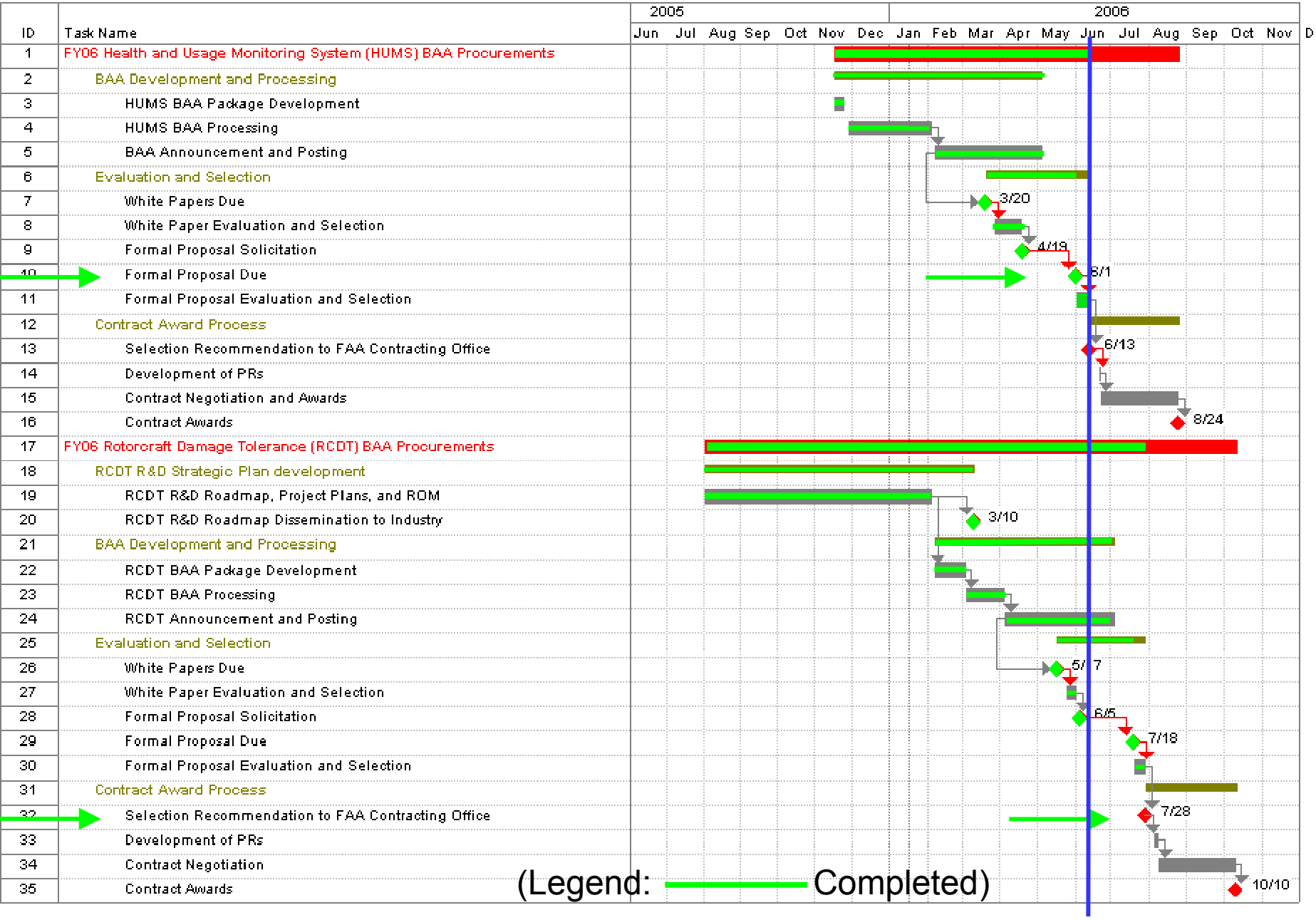
- Requirements for onboard advisory/warning and display systems or devices
- Guidelines for pilots or ground-based personnel required to respond to onboard advisories and warnings

Onboard Warnings
- Responses and Procedures -



HUMS CATEGORIES	YEARS AND ROM ($K)											
	1	2	3	4	5	6	7	8	9	10	11+	TOTAL
HUMS AC REQUIREMENT COMPLIANCE AND DEMONSTRATION	**248**	**496**	**496**	**496**	**490**	**485**	**485**	**242**	**0**	**0**	**0**	**3438**
Usage and Flight Regime Recognition	248	248	248	248								992
Direct Load Measuring		248	248	248	248							992
Maintenance Credit Demonstration					242	485	485	242				1454
DEVELOPMENT OF HUMS OPERATION REQUIREMENTS	**1257**	**1775**	**1518**	**1498**	**1341**	**855**	**514**	**298**	**336**	**267**	**276**	**9935**
Hardware	**757**	**1159**	**1090**	**948**	**629**	**193**	**104**	**71**	**206**	**137**	**276**	**5570**
Sensors	412	814	814	501	214	89		71	137	137	276	3465
Airborne Systems	172	172	137	137	137	41	41					837
Ground Stations and Peripherals	173	173	139	310	278	63	63		69			1268
Software	**500**	**616**	**428**	**550**	**712**	**662**	**410**	**227**	**130**	**130**	**0**	**4365**
Data Management and Operation	188	304	116	370	532	532	235	97				2374
Diagnostics And Monitoring	312	312	312	180	180	130	175	130	130	130		1991
Maintenance Management								22				22
COMMERCIAL VALIDATION OF HUMS	**455**	**455**	**455**	**215**	**166**	**83**	**214**	**298**	**263**	**197**	**0**	**2801**
Algorithm and Methodologies	**455**	**455**	**455**	**215**	**166**	**83**	**214**	**298**	**263**	**197**	**0**	**2801**
Safety Monitoring							104	35				139
Structural Usage Monitoring and Credit Validation	329	329	329	89	22			198	198	132		1626
Diagnostics, Health, and/or Prognostics	126	126	126	126	144	83	110	65	65	65		1036
Continued Airworthiness Instructions												**0**
ONBOARD WARNINGS	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**485**	**0**	**0**	**0**	**485**
Flight and Ground Crew								485				485
TOTAL ROM:	1960	2726	2469	2209	1997	1423	1213	1323	599	464	276	16659

RCDT & HUMS BAA Process & Milestones



Email: Dy.Le@faa.gov
Phone: (609) 485-4636
Fax: (609) 485-4004

www.ato.faa.gov

http://airportaircraftsafetyrd.tc.faa.gov

Questions?